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14. ABSTRACT

The Tactical Medical Logistics Planning Tool (TML+) is a software program designed for Navy and Marine Corps medical planners as a tool that (1) models the patient flow from the point of injury through more definitive care, and (2) supports operations research and systems analysis studies, operational risk assessment, and field medical services planning. TML+ is designed with a user-friendly graphic user interface, an open architecture, and four program modules. The casualty generation module uses an exponential distribution to stochastically generate wounded in action, disease, and nonbattle injuries. The care providing module uses generic task sequences, simulated treatment times, and personnel, consumable supply, and equipment requirements to model patient treatment and queuing within a functional area. The network/transportation module simulates the evacuation (including queuing) and routing of patients through the network of care via transportation assets. The reporting module produces an Access database detailing myriad metrics, such as patient disposition, time-in-system data, and consumable, equipment, personnel and transportation usage, which can be filtered according to the user's needs. TML+ can be used before deployment as a deliberate planning tool or during deployment as a crisis-action tool that assists planners in responding to the rapidly changing wartime environment.

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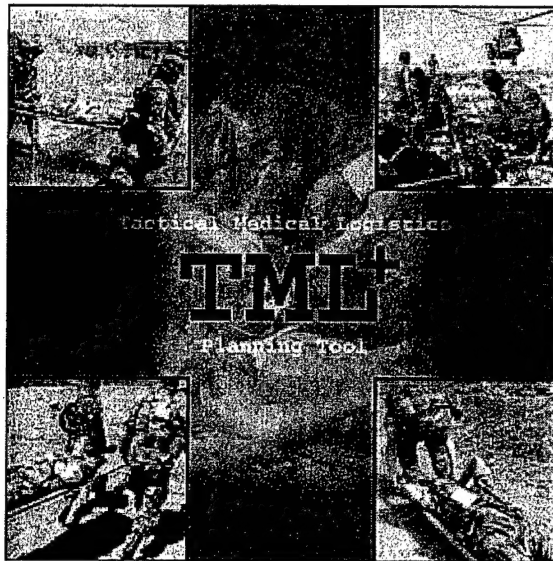
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ABSTRACT

The Tactical Medical Logistics Planning Tool (TML+) is a software program designed for Navy and Marine Corps medical planners as a tool that (1) models the patient flow from the point of injury through more definitive care, and (2) supports operations research and systems analysis studies, operational risk assessment, and field medical services planning. TML+ is designed with a user-friendly graphic user interface, an open architecture, and four program modules. The casualty generation module uses an exponential distribution to stochastically generate wounded in action, disease, and nonbattle injuries. The care providing module uses generic task sequences, simulated treatment times, and personnel, consumable supply, and equipment requirements to model patient treatment and queuing within a functional area. The network/transportation module simulates the evacuation (including queuing) and routing of patients through the network of care via transportation assets. The reporting module produces an Access database detailing various metrics, such as patient disposition, time-in-system data, and consumable, equipment, personnel and transportation utilization rates, which can be filtered according to the user's needs. TML+ can be used before deployment as a deliberate planning tool or during deployment as a crisis-action tool that assists planners in responding to the rapidly changing wartime environment.

INTRODUCTION

The United States Marine Corps (USMC) has changed its doctrine and policy to achieve more flexible and effective combat operations. To accomplish this goal (as expressed in Operational Maneuver from the Sea), Concept of Naval Force Medical Protection for the 21st Century, Joint Vision 2020, Marine Corps Strategy 21, and Sea Power 21 illustrate the need for highly mobile medical units with improved responsiveness. This doctrine requires new tools to assist in deliberate and crisis-action tactical and medical planning for the rapidly changing warfighting environment.

In answer to this need, the Naval Health Research Center (NHRC) and Teledyne Brown Engineering (TBE) developed the Tactical Medical Logistics Planning Tool (TML+). TML+ is a software program designed for Navy and Marine Corps medical planners as (1) a simulation tool that models the flow of patients from the point of injury through more definitive care, and (2) a research tool that supports operations research and systems analysis studies, operational risk assessment, and field medical services planning.

BACKGROUND

In response to changing warfighting doctrine, the Marine Corps Combat Development Command (MCCDC) and the Marine Corps Systems Command (MARCORSYSCOM) developed the Forward Resuscitative Surgery System (FRSS). Marine Corps concepts and doctrine state that warfighting will require increased mobility and dispersion, and reflect a higher tempo of operations among combat elements. These goals require medical assets to achieve greater mobility and faster response without compromising the high level of care traditionally administered.

In response to these needs, FRSS is designed as a highly mobile, rapidly deployable, trauma surgical unit that provides emergency surgical interventions required to stabilize

casualties who might otherwise die or lose limbs before reaching treatment. FRSS may be used as the initial surgical capability ashore in the traditional amphibious assault, or it may be the only surgical capability ashore, as in an Operational Maneuver From the Sea scenario. FRSS is designed to respond to the demands of rapid phase changes that require the ability to shift operational objectives quickly and efficiently. To meet this mission, FRSS requires a small logistical footprint that supports early introduction into the operating area, rapid movement, deployment, and re-deployment in forward areas.

Introducing this new capability into the Marine Corps continuum of care has raised many questions as to its impact on medical treatment and resources. Therefore, MARCORSYSCOM sponsored an effort to represent the medical assets required to support FRSS in all stages of operations. Assisting in this effort, NHRC developed TML+ as a tool to research how FRSS could most efficiently use medical resources such as supplies, personnel, and transportation to provide patients with the best protection and medical care possible. As TML+ was designed, it was expanded to model additional medical treatment facilities, including the First Responder, Battalion Aid Station (BAS), FRSS, Shock Trauma Platoon (STP), Surgical Company (SC), and Casualty Receiving and Treatment Ship (CRTS), and is currently being expanded to include additional theater platforms both shipboard and ashore.

LITERATURE REVIEW

Modeling and simulation software has long been integral to the Navy's preparation for contingencies. The Navy has designed programs addressing issues specific to warfighting and specific to the medical needs of a mission. Examples of the Navy's warfighting modeling software includes the Joint Warfare System (JWARS), Joint Semi-Automated Forces (JSAF), and Expeditionary Logistics Support System (EXLOGSS).

JWARS is a program developed to model the warfighting requirements within a joint theater of operations, simulating the combat, maneuvering, and movement of units and supplies across land, air, and sea. Using a decision tree structure, JWARS models direct and indirect fire engagements, the formations of units when moving, assembling, attacking, and defending, and communications across units. In addition, JWARS models the supply and resupply requirements necessary to sustain a warfighting mission, scheduling supply delivery of fuel and ammunition via transportation assets according to how the scenario unfolds within the simulation (Joint Warfare Systems Office, 2003). JWARS is valuable for operational planning and execution, force assessment studies, systems effectiveness and trade-off analyses for a warfighting mission (Stone and McIntyre, 2001).

JSAF is a program designed to model the complex integration of all branches of the military (Army, Air Force, Marines, and Navy) in the execution of a warfighting mission. JSAF generates elements of a contingency, such as troops, tanks, ships, airplanes, munitions, buildings, and sensors, which interact within the constraints of a combat environment. The synthetic environment is a representation of terrain, oceans, and weather conditions that affect the decision, interactions, and capabilities of joint forces ("Information"). JSAF was later expanded to include a medical component called Joint Medical Semi-Automated Forces (JMedSAF), which provides medical planning and rehearsal within a joint environment. JMedSAF simulates force-on-force interactions and models the treatment, transportation, and evacuation of the resulting casualties according to joint doctrine (Hardy et. al., 2001).

EXLOGSS is designed as a logistics planning tool for the Marine Corps that forecasts the food, water, fuel, and ammunition requirements for each warfighting unit for each day within a mission. In addition to projecting the types and quantities of these supplies, EXLOGSS determines a resupply schedule that both itemizes the delivery of supplies from ship to shore for a mix of transportation assets (helicopters, Ospreys, trucks) and assesses the feasibility of this schedule within the scenario constraints (Metron, Inc., unpublished presentation).

However, to ensure the success of a warfighting mission, the Navy must have the required medical resources necessary to support the operation. As a result, the Navy has developed software that models the medical component of a contingency so that medical planners and logisticians can research how to provide the best medical treatment possible within the constraints of a scenario. Such medical programs include the Ground Casualty Projection System (FORECAS), the Estimating Supplies Program (ESP), and the Medical Analysis Tool (MAT).

FORECAS is a software program developed by NHRC that is designed to provide medical planners with the estimates of the average daily rates of wounded in action (WIA) and nonbattle injury (NBI) patients during a specific scenario. NHRC developed these rates primarily based on the analysis of historical accounts of ground operations. A deterministic model, FORECAS assists medical providers by projecting the distribution of injuries and illnesses likely to occur within different warfighting environments (Blood et. al., 2003).

ESP is a program developed by NHRC for three purposes. First, ESP can be used as an estimation tool that projects the quantities (including weight, cube, and cost) and combinations of consumable supplies and equipment necessary to support the needs of a patient stream throughout the continuum of care. Second, ESP can be used as a decision tool that evaluates inventory readiness by assessing which supplies are missing and how these missing supplies affect medical treatment options. Third, ESP is a mapping and training tool that illustrates the relationship among PCs, tasks, supplies, and areas of care. As a deterministic model, ESP is most useful for generating the supplies needed to treat a user-defined patient distribution (Tropeano and Konoske, 2002).

MAT is designed as planning tool for the joint environment. Medical planners use MAT to both generate the medical requirements required to support patient treatment within a joint warfighting operation as well as develop and evaluate courses of action for this operation. As a tool for both deliberate and crisis-action planning, MAT determines the number of beds, the number of operating room tables, number and types of personnel, and the amount of blood required to treat the casualty stream. MAT also identifies bottlenecks within the system and assesses risk associated with the designated medical treatment facilities (Marghella, 2003).

Each of these programs provides useful information for preparing for a mission; however, there is still the need to model the flow of casualties within a specific network of treatment facilities from the generation of casualties through the treatment system, simulating the treatment times and demands on consumable supplies, equipment, personnel, and transportation assets in the far-forward environment. TML+ fills this need specifically for the Marine Corps and Navy, and could be expanded to include the data for a joint environment.

DESCRIPTION OF TML+

To simulate the flow of patients, the user enters the length of the scenario, enters the mean numbers of WIA, disease (DIS), and NBI expected to occur, and builds a treatment network

by selecting the types and locations of levels of care and the transportation assets expected to evacuate patients. With these inputs, TML$^+$ uses stochastic processes to model patient arrivals, treatment, and outcomes as they flow from the point of injury (POI) through a network of care facilities. TML+ currently:

- generates a stream of patients occurring randomly in time and space among POIs.

- generates the specific patient conditions (PCs) for each patient.

- prioritizes the treatment and evacuation of patients based on the severity of injuries.

- models mortality as killed in action, died of wounds as a function of complications, and died of wounds due to a delay in treatment.

- simulates patient flow through levels of care (LOCs), including arrival times, wait times, and treatment times.

- models the routing and utilization of transportation assets.

- generates dynamic reports in graph and tabular formats that show the status of the medical treatment facilities, patient disposition, and resource utilization.

To successfully execute these functions, TML+ has a significant amount of underlying data that includes over 400 PCs developed by the Joint Readiness Clinical Advisory Board and NHRC; medical treatment tasks; task sequences; treatment times; consumable supplies and equipment; weight, cube, and cost of each supply item; died of wounds due to time; died of wounds due to complications; type, speed, and capacity of transportation assets; levels of care and their respective functional areas; number of personnel; and personnel skill sets.

METHODOLOGY

The methodology used to develop TML+ has three principal features: a Windows-based graphic user interface, an open architecture, and a four-module program structure.

GRAPHIC USER INTERFACE (GUI)

TML+ was designed as a user-friendly program with a Windows-based interface (see Figure 1). The GUI has four primary parts: the Scenario Explorer, the Common Data Explorer, the Properties box, and the Network View. The Scenario Explorer displays the user's inputs for the treatment network while the Common Data Explorer shows the programs predefined levels of care and transportation assets as well as their underlying data. The Properties box displays specific attributes of the selected item and the Network View provides a graphic representation of the treatment network.
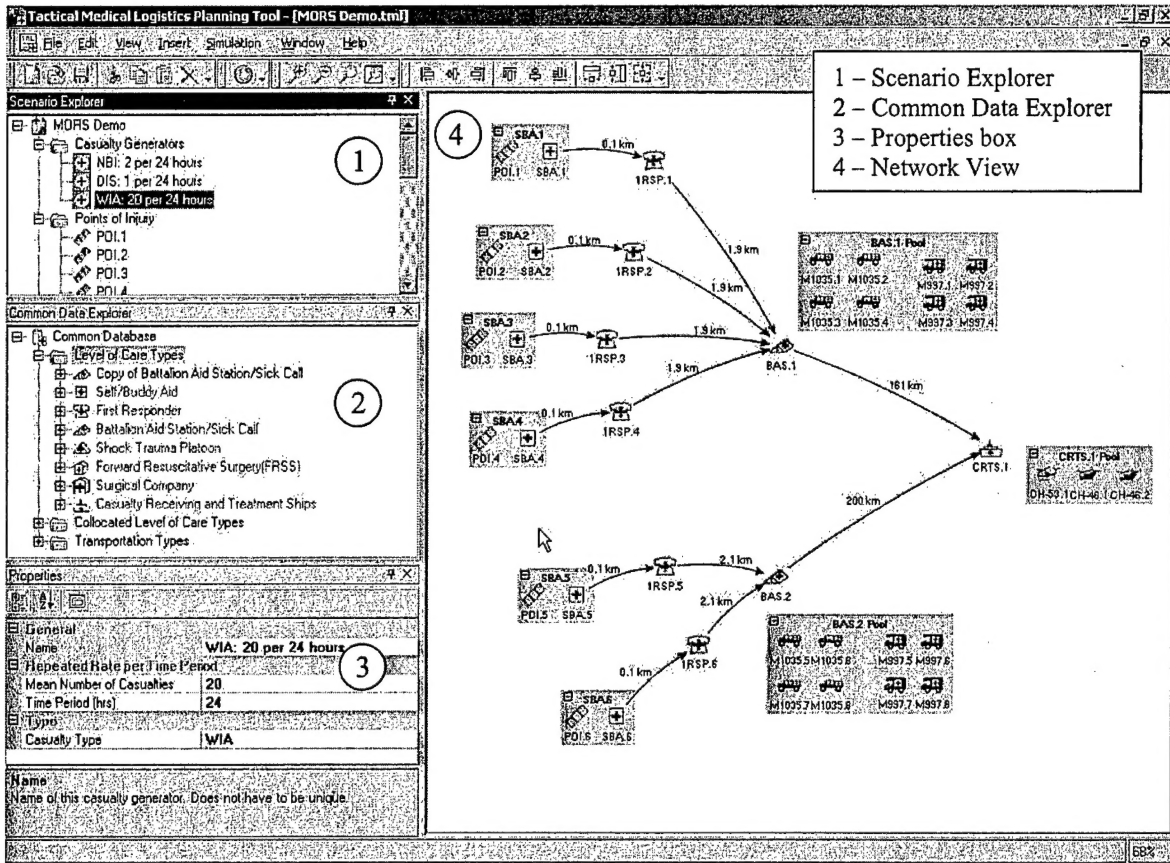
Figure 1. TML+ GUI

The user drags and drops the LOC and transportation icons from the Common Data Explorer onto the Network view, then connects these assets by drawing lines between the icons to establish the primary and secondary routes the patients travel. Once this treatment network is built, the user uses the Scenario Explorer in conjunction with the Properties box to input the length of the scenario, the theater of operations, and the number of WIA, DIS, NBI, and KIAs expected to occur during the scenario.

ARCHITECTURE

TML+ was designed as a non-proprietary program to be distributed to a multitude of users. In addition, TML+ has an open architecture built using C++ programming and the C#.net framework that can be expanded to include additional aspects of medical modeling (such as new treatment facilities, transportation assets, and personnel). This flexible architecture allows TML+ to be tailored to any type of warfighting environment.

FOUR TML+ MODULES

TML+ is a discrete event simulation program in which discrete units of traffic (in this case, patients) move from point to point in the system while competing with each other for the

use of resources (personnel, equipment, consumable supplies, and transportation assets). TML+ has four modules: casualty generation, care providing, network/transportation, and reporting.

Module 1 - Casualty Generation

There are three ways to generate casualties: repeatable rate, table rate, and a user-defined casualty stream. The repeatable rate is the number of casualties expected to occur within a certain number of hours. The user enters the type of casualties (WIA, DIS, NBI), the mean number of casualties, and the time period within which they are expected to occur. This rate is repeated for the length of the scenario. For example, if a user enters a mean number of 12 WIAs every 24 hours, then approximately 36 WIAs are stochastically generated for a 72-hour scenario.

TML+ assumes that casualties occur randomly in time according to a Poisson process where the inter-arrival time—the time between patient arrivals—is given by a random variable. TML+ stochastically generates the inter-arrival time based on an exponential distribution. An exponential distribution is defined as follows:

$$f(x) = \begin{cases} \dfrac{1}{\theta} e^{-x/\theta} & for \quad x > 0 \\ 0 & elsewhere \end{cases}$$

where $\theta > 0$ is a constant, the mean of x is θ, and the variance of x is θ^2.

Exponential random variables are often associated with a waiting time that precedes the occurrence of certain specific events. For instance, the time that precedes an injury is a random variable that may reasonably be assumed to be exponential (Strait, 1983). The derivation of the equation for randomly generating an exponentially distributed number follows (Abramowitz and Stegun, 1972):

$$F(y) = \int_0^y f(x)dx$$

$$F(y) = \int_0^y \frac{1}{\theta} e^{-x/\theta} dx$$

$$F(y) = -e^{-y/\theta} + 1$$

$$F(y) - 1 = -e^{-y/\theta}$$

$$1 - F(y) = e^{-y/\theta}$$

$$\ln(1 - F(Y)) = -y/\theta$$

$$y = -\theta \ln(1 - F(Y))$$

Note that 1-F(Y) and F(Y) are both uniformly distributed over the interval 0 to 1. Therefore the equation becomes $y = -\theta \ln F(Y)$ where F(Y) is a uniformly distributed number over the interval 0 to 1. The quantity "y" is the desired random inter-arrival outcome.

The algorithm for the repeatable rate is:

IAT_m = Period / MeanNumber;
Repeat
       IAT_i = Exponential (IAT_m, Uniform Random Number)
       $AT_i = AT_{i-1} + IAT_i$
Until $AT_i > t_{end}$

Where Period is the time period in hours,
MeanNumber is the mean number of casualties assumed over the period,
IAT_m is mean inter-arrival time (θ above),
IAT_i is inter-arrival time for casualty i,
AT_i is arrival time for casualty i, and
t_{end} is the scenario's end time.

The table rate allows the user to input different casualty rates across a collection of time periods, providing the ability to model the pulses and pauses in patient flow. Unlike the rate option, the numbers the user enters are generated once. Table 1 is a sample table rate casualty generator. From this input, TML+ would stochastically generate a mean of 2 casualties from hour 0 to hour 24:00, a mean of 3 from hour 24:01 to hour 48:00, and mean of 10 from hour 48:01 to hour 50:00.

Table 1. Sample table rate casualty generator

Casualty Type: WIA	
Mean Number of Casualties	Ending Time Period (hrs)
2	24
3	48
10	50
7	70
4	72

The algorithm used for the table rate is:

For n=1 to number of entries in table
    IAT_n = (EndTime$_n$ – StartTime$_n$) / MeanNumber$_n$
    Repeat
        IAT_i = Exponential (IAT_n, Uniform Random Number)
        $AT_i = AT_{i-1} + IAT_i$
    Until $AT_i > EndTime_n$ or $AT_i > t_{end}$

Where StartTime$_n$ is start time for table entry n,
EndTime$_n$ is end time for table entry n,
MeanNumber$_n$ is mean number of casualties for table entry n,
IAT_n is mean interarrival time for table entry n,

IAT$_i$ is interarrival time for casualty i,
AT$_i$ is arrival time for casualty i, and
t$_{end}$ is the scenario's end time.

The user-defined casualty generator offers the greatest control of the patient stream for the user. The user defines each casualty type, the specific PC code of the casualty, when it arrives into the system (in minutes), and the POI at which it occurs. Table 2 shows a sample user-defined casualty generator.

Table 2. Sample user-defined casualty generator

Casualty Type	Arrival Time	Patient Code	POI
WIA	2.0	68	POI1
WIA	5.0	178	POI1
WIA	25.0	55	POI2
NBI	38.0	32	POI1
DIS	39.1	166	POI1

Killed in action (KIA) casualties are determined by two criteria: the user-defined ratio and the Bernoulli probability function. First, the user enters a ratio of the amount of killed troops per group of injuries (for example, 1 KIA per 10 WIAs). To appropriately simulate battle, KIA is drawn only from WIA casualties. Then, within the parameters of the identified KIA ratio, TML+ uses the Bernoulli probability function to determine when a WIA casualty is simulated to be KIA. The Bernoulli probability function has two possible outcomes, success or failure. In TML+, if the random variable x takes on the value 1, the Bernoulli trial is a success; if x takes on the value 0, the Bernoulli trial is a failure. If p is the probability of success and $q = 1 - p$ is the probability of failure, the probability density function of X is

$$f(x) = \begin{cases} p & if \quad x = 1 \\ q & if \quad x = 0 \end{cases}$$

where $0 < p < 1$ and $p + q = 1$. TML+ returns true when RN $<= p$ where p is the probability of success and RN is a uniform random number.

Casualties generated by the repeatable rate and table rate methods (the first two methods discussed above) that are not designated KIA are assigned a PC. In randomly generating the PC code of each patient, TML+ uses probabilities developed by NHRC where the individual PC probabilities sum to unity. To develop these rates, NHRC extracted data from historical accounts of ground operations, adjusted the data for factors such as recency of operation and medical advances, and computed the rates for battle intensity levels light, moderate, heavy, and intense (Blood et. al., 2002). TML+ simulates a PC outcome for a particular casualty by comparing a randomly chosen value of the uniform distribution to the cumulative probability distribution of PC values determined by NHRC.

Module 2 - Care Providing

Once the casualty stream is generated, TML+ simulates the treatment of patients through a network of levels of care with varying medical capability. A level of care is defined as a facility with one or more functional areas while a functional area is defined by the personnel, equipment, and consumable supplies assigned to establish its medical capability. Figure 2 is a representation of the care providing process. There are two primary aspects of the Care Providing module: treatment and queuing. The patient arrives at the functional area and queues for treatment, as denoted by the first shaded box in Figure 2. When the required assets become available, the patient proceeds into the functional area to receive treatment, as depicted by the lower part of the graphic.
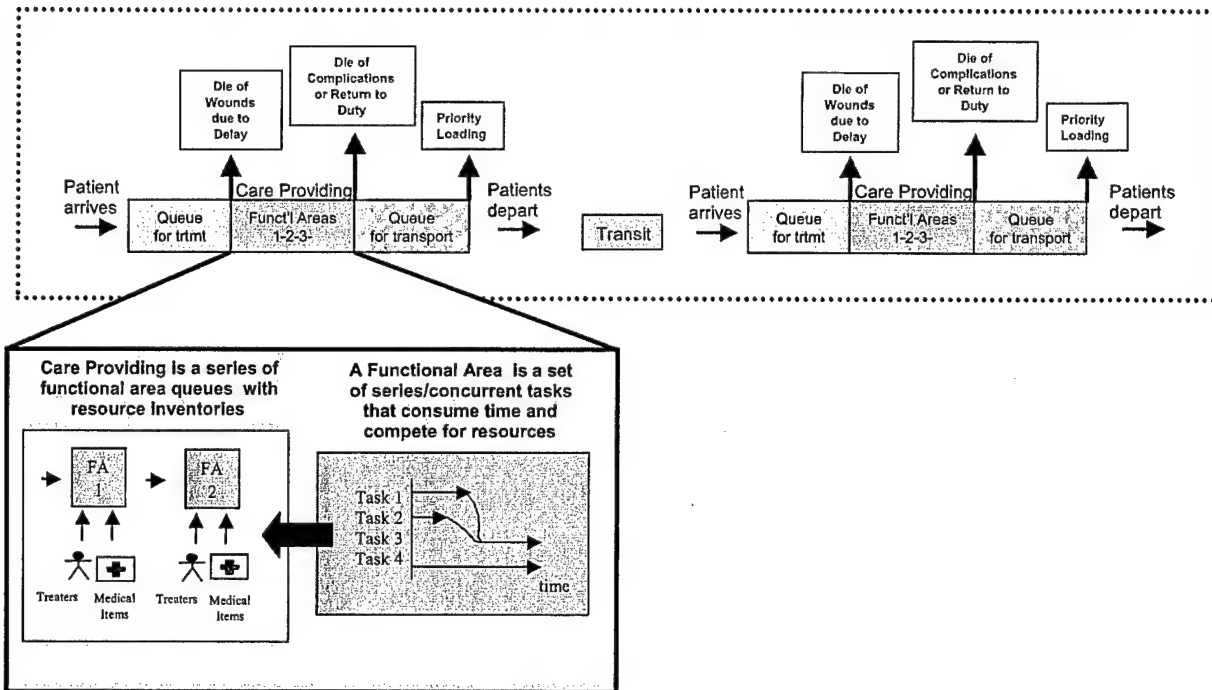

Figure 2. Care Providing Within the Treatment Network

Treatment

Treatment is defined as the series of medical tasks required to treat a specific PC. Each PC is linked to a set of medical tasks, and each medical task is linked to the consumable supplies, equipment (including quantity, weight, cube and cost) and personnel required to accomplish that task. When the personnel and equipment required to treat the specific PC are available, treatment begins. (Consumable supply inventory is tabulated as the patient receives treatment and is therefore not a constraint in the current version of TML+. See section Generic Task Sequence below for more information.)

Generic Task Sequence. Each functional area has a generic task sequence (GTS), which defines the order in which medical tasks are performed to provide treatment to a casualty (see Figure 3 for the GTS for the First Responder). In other words, the GTS orders all the medical
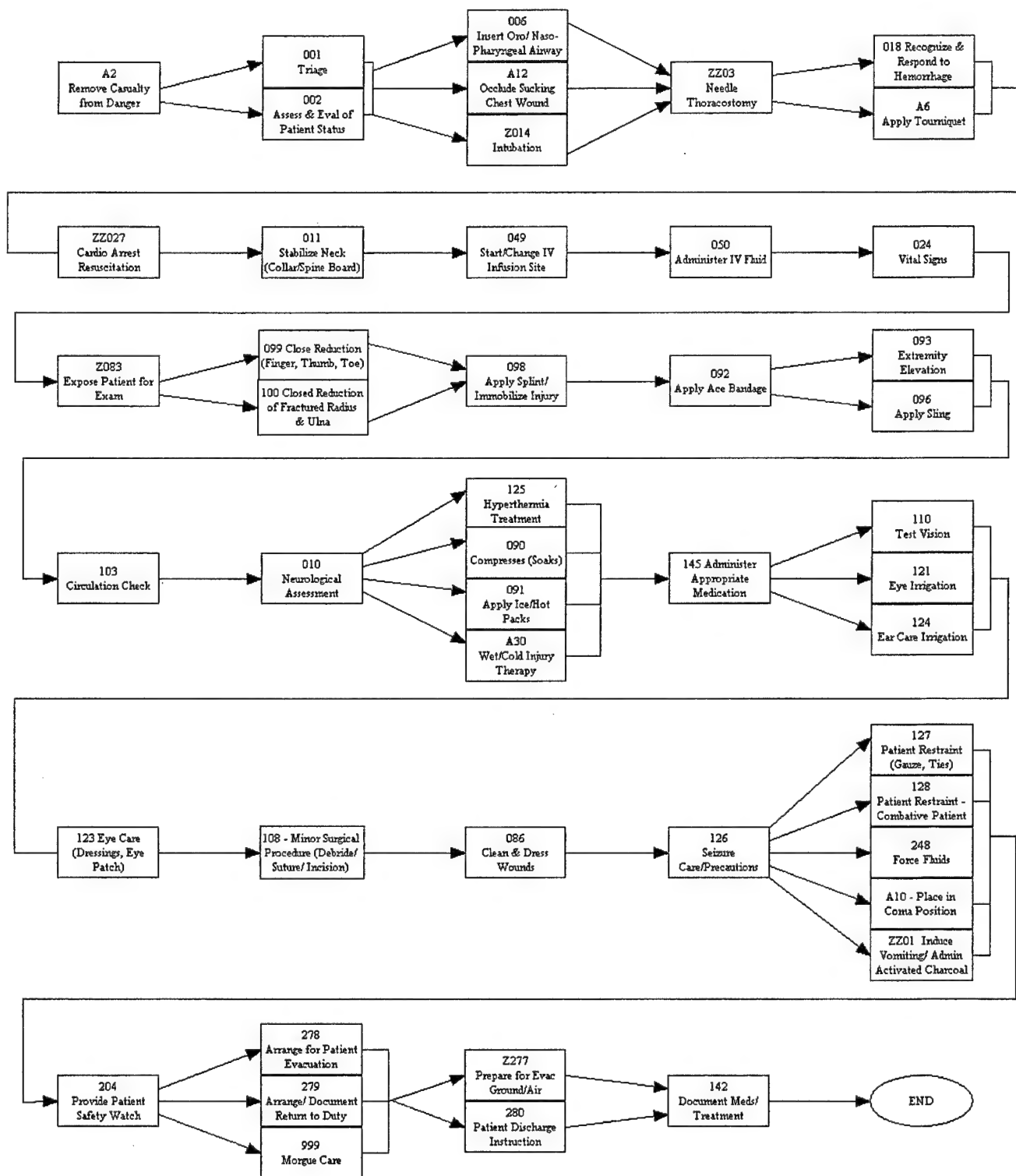
A2 Remove Casualty from Danger → **001** Triage / **002** Assess & Eval of Patient Status → **006** Insert Oro/ Naso-Pharyngeal Airway / **A12** Occlude Sucking Chest Wound / **Z014** Intubation → **ZZ03** Needle Thoracostomy → **018** Recognize & Respond to Hemorrhage / **A6** Apply Tourniquet

ZZ027 Cardio Arrest Resuscitation → **011** Stabilize Neck (Collar/Spine Board) → **049** Start/Change IV Infusion Site → **050** Administer IV Fluid → **024** Vital Signs

Z083 Expose Patient for Exam → **099** Close Reduction (Finger, Thumb, Toe) / **100** Closed Reduction of Fractured Radius & Ulna → **098** Apply Splint/ Immobilize Injury → **092** Apply Ace Bandage → **093** Extremity Elevation / **096** Apply Sling

103 Circulation Check → **010** Neurological Assessment → **125** Hyperthermia Treatment / **090** Compresses (Soaks) / **091** Apply Ice/Hot Packs / **A30** Wet/Cold Injury Therapy → **145** Administer Appropriate Medication → **110** Test Vision / **121** Eye Irrigation / **124** Ear Care Irrigation

123 Eye Care (Dressings, Eye Patch) → **108** - Minor Surgical Procedure (Debride/ Suture/ Incision) → **086** Clean & Dress Wounds → **126** Seizure Care/Precautions → **127** Patient Restraint (Gauze, Ties) / **128** Patient Restraint - Combative Patient / **248** Force Fluids / **A10** - Place in Coma Position / **ZZ01** Induce Vomiting/ Admin Activated Charcoal

204 Provide Patient Safety Watch → **278** Arrange for Patient Evacuation / **279** Arrange/ Document Return to Duty / **999** Morgue Care → **Z277** Prepare for Evac Ground/Air / **280** Patient Discharge Instruction → **142** Document Meds/ Treatment → **END**

Figure 3. GTS for First Responder

tasks performed on *all* the PCs treated at that functional area. When a patient arrives at the functional area, the tasks associated with the specific PC are correlated against the functional area's GTS; the subset of medical tasks required to treat the specific PC are performed in the order designated by the GTS. As the patient proceeds through the GTS, TML+ assigns the personnel and equipment required by each task for the duration of that task's completion so that it cannot be assigned to another patient. When the task is complete, those resources are freed and returned to the equipment and personnel pool. In addition, the consumable supply quantities are decremented from the functional area inventory. When the inventory is exhausted, TML+ continues to track inventory consumption into negative amounts to make visible the quantity the inventory was short in treating the patient stream.

Simulated Treatment Time. Treatment time in a particular functional area or LOC is defined as the total time to perform a set of tasks plus the waiting time that may be associated with each task. The simulated treatment time of the patients is based on three factors. First, each task has an average task time assigned to it. As the patient proceeds through the GTS, a random task time is calculated for each task based upon the exponential distribution using the average task time for that specific task (the same algorithm used to generate casualty inter-arrival times).

Second, there are four types of tasks within the GTS: sequential, concurrent, continuous, and repeated:

- Sequential tasks are those that are performed one after another.

- Concurrent tasks are those that are completed simultaneously.

- Continuous tasks are those that use equipment for the patient's length of stay in that functional area.

- Repeated tasks are those that are performed more than once during the patient's stay at the functional area (for example, checking blood pressure every 4 hours in post-operative care).

The types of tasks completed to treat the PC influence the aggregated total treatment time across the tasks in a functional area. For example, referring back to Figure 2, tasks 1 and 2 are concurrent tasks while task 3 is a sequential task. The time required to complete tasks 1 and 2 is shorter than if they were sequential tasks because they occur simultaneously.

Third, treatment time is also influenced by the availability of assets. If the intensity of the casualty flow is high, the patients must wait for equipment and personnel assets. This wait time increases the average treatment time, indicating that the treatment network requires more assets to alleviate the accumulation of patients waiting for treatment.

Queuing

Patient queuing occurs in two places within the care providing module: before treatment begins and during treatment. Before treatment begins, when a patient arrives at a functional area, TML+ determines if the available personnel and equipment are available to perform the first task. If the medical resources are assigned a busy status, the patient is placed into a waiting pool. TML+ offers two types of service disciplines (who enters service first if several casualties are waiting); the user can either choose to treat patients on a first-in-first-out (FIFO) basis, which treats the

casualty who has been waiting the longest, or a Priority basis, where the casualty with the highest severity is selected to receive treatment first. If FIFO is selected, patients entering the waiting pool are rank ordered based on arrival time. If Priority is selected, patients are rank ordered on the severity of the PC and arrival time.

When the assets needed to perform the first task are available, the patient moves from the waiting pool into the functional area and task treatment begins. For each subsequent task in the GTS, TML+ performs the same test to determine the availability of the required personnel and equipment assets—a patient cannot proceed to the next task until the necessary assets are free. Each task is assigned two personnel types, the default provider, which is the best-case provider, and the minimum provider, who has the skills necessary to complete the task. If the default provider is busy, TML+ determines if the minimum provider is available. If the minimum provider is also busy, the patient goes back into the waiting pool. Likewise, if the equipment items necessary to treat the PC are busy, the patient is placed back into the waiting pool, ordered by the severity of the PC and arrival time.

Patient Disposition. The patient disposition is checked at two points in the functional area, at the beginning and end of treatment. Referring back to Figure 2, TML+ determines at the beginning of the GTS if the patient has died of wounds due to a delay in the start of treatment. An algorithm, developed from subject matter expert data that analyzed the deterioration of a patient who goes without treatment, gives a probability of survival (death) that can be compared to a simulated uniform random number. Based on the PC code and time since injury, the algorithm models the survival (or death) of the casualty at that specific point in the scenario.

Second, after treatment is completed, the final set of tasks in the GTS, called disposition tasks, determines the patient's outcome (died of complications, returned to duty, transferred to the next functional area, or evacuated to the next level of care). Each disposition task for a PC has a probability of occurrence and the set sums to unity. A simulated uniform random number compared to the cumulative distribution of these four outcomes determines which disposition task is chosen for that specific patient.

Module 3 – Network/Transportation

The network/transportation module has four aspects: a treatment network definition that connects the LOCs, transportation assets that link these LOCs, transportation routing, and patient queueing for transport.

Treatment Network Definition

The user defines a treatment network by first selecting one of five canned configurations:

1. First Responder to BAS to CRTS
2. First Responder to BAS to SC to CRTS
3. First Responder to BAS to FRSS to CRTS
4. First Responder to BAS/STP to CRTS
5. First Responder to STP/FRSS to CRTS

Figure 4 shows an example of configuration 3. The user can use the original five configurations or build on them by adding or modifying LOCs to represent more sophisticated

and realistic treatment networks for various tactical scenarios. As shown in Figure 3, all configurations in TML+ assume the surviving casualty proceeds from a POI, where Self/Buddy Aid is received, to a First Responder location.
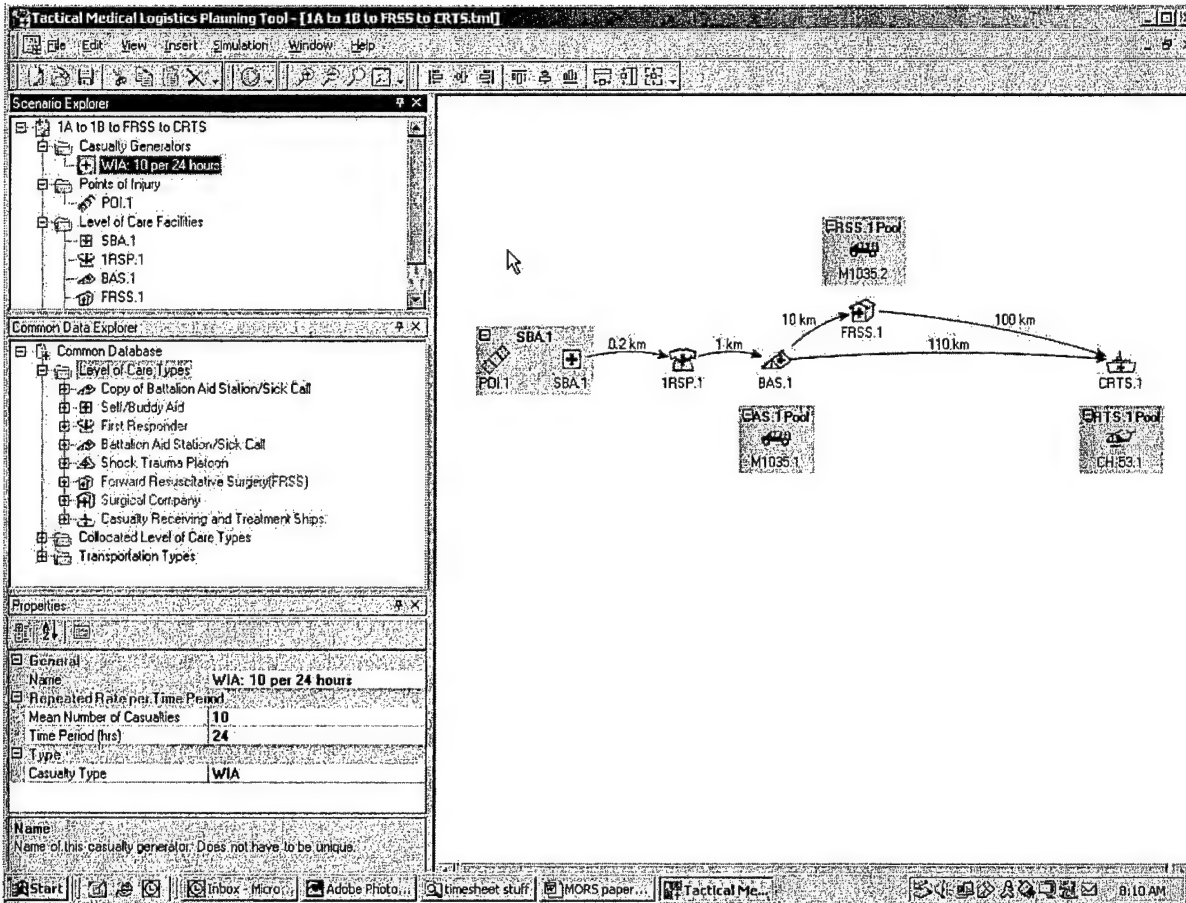

Figure 4. Sample TML+ Network Configuration: First Responder to BAS to FRSS to CRTS.

Transportation Assets

The user identifies the transportation assets for each LOC added to the treatment network. Each transportation asset is defined by an empty speed, a loaded speed, a maximum litter capacity, a maximum ambulatory capacity (2 ambulatory seats equal 1 litter space), patient loading and unloading time, and a maximum wait time that the transporter remains grounded waiting for a full patient load. Each of these aspects of the transporter can be modified by the user.

Transportation Routing

The patient flows through the treatment network via transportation assets according to two types of routing rules: primary and secondary. The routes are denoted by lines that connect the LOCs; for example, in Figure 4, the line connecting BAS to FRSS is a primary route while

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the line connecting BAS to CRTS is a secondary route. The primary routes are thus established by the user's definition of the treatment network and the rules defined in TML+ data restrict the path patients may travel based on the medical capabilities of the selected LOCs and functional areas as defined by Navy and Marine Corps doctrine. For example, a primary routing rule restricts patients from being evacuated from POI to BAS; it is assumed patients always receives treatment from a First Responder before evacuation.

The secondary routes are determined by three steps. First, TML+ checks to determine if patient's PC is treated at the next LOC. If no, the patient is queued for evacuation as described in the next section. If yes, TML+ next checks to determine if the LOC has a busy status, meaning that the patient capacity of the LOC has been reached and a certain quantity of patients (as designated by NHRC according to doctrine) are waiting for treatment. For example, if both beds in FRSS operating room are busy and two patients are waiting for treatment, FRSS has a busy status and patients are routed to the next LOC. If the LOC is busy, the patient is queued for evacuation. If the LOC is free, TML+ stochastically determines by a random draw whether the patient is treated at that LOC. Because not all PCs are treated at every functional area, this random draw is based on the percentage of patients with a specific PC that are treated at a specific functional area.

Using Figure 4 as an example, if a patient with a surgical PC arrives at BAS, the primary routing rules determine the patient be evacuated from BAS to FRSS. However, if FRSS has a busy status at the time the patient arrives, the patient will queue to be evacuated to CRTS. If FRSS is free, TML+ executes a random draw to determine if FRSS treats the patient or is evacuated to CRTS because only a percentage of those patients with that surgical PC are treated at FRSS.

Patient Queuing for Transport

Patient queuing begins when the evacuation call for the patient occurs. An evacuation call is placed when the patient reaches the task in the GTS that determines an evacuation disposition. TML+ checks the availability of transportation assets, which are prioritized by empty speed and capacity with the fastest and largest being called first to evacuate patients. In addition, the availability of the asset is determined by assessing all the demands made on that asset; the asset services the LOC with the highest priority casualty waiting to be evacuated.

If the asset is busy, the patient queues for transport according to the service discipline, either FIFO or Priority. Patients entering the waiting pool are rank ordered based on arrival time. or on the severity of the PC and arrival time, respectively.

If the asset is available, the patient is assigned a claimed status and the capacity of the asset is decremented based on the PC's designation as a litter or ambulatory. When the transportation asset reaches full capacity, it is assigned a busy status, which precludes it from being called for a subsequent evacuation run until its present assignment is completed. Travel time to the LOC is determined by dividing the distance to be traveled by the transporter's unloaded speed.

Module 4 - Reporting

There are three layers of data in the Reporting module in TML+: raw database tables, stored queries, and queries within the GUI. TML+ outputs raw results to a Microsoft Access database. This database is then interpreted by stored queries in the report database. These stored

queries then present the data in the report viewer in the GUI; the report viewer is dynamic, allowing the user to easily manipulate the output to view the desired data through drop-down menus and filtering options.

Table 3 lists a selection of the reports available in TML+ including the available formats of each report, the information contained in each report, and why each report is useful. To improve accuracy and make the addition of new reports easier, several different reports may interpret the same data in different ways. Whenever possible, several reports share the same set of data to reduce potential errors.

Table 3. List of Reports in TML+

Report	Formats	Information in Report	Value to Medical Planners
General Information			
Scenario properties	Table	Shows all the user inputs for the scenario	
Audit report	Table	Displays each process completed by TML+ (a very extensive report)	Used by NHRC for testing purposes
All assumptions	Table	Lists all the underlying assumptions for TML+	
Casualty Generation			
Patients by type	Table, pie chart	Shows the numbers of WIA, KIA, NBI, and DIS.	Provides visibility of the distribution of the types of casualties in the patient stream.
Patients by disposition	Table, pie chart	Shows the total numbers of died of wounds, died of complications, returned to duty, still in system, and evacuated across all levels of care.	Provides visibility of the distribution of patient dispositions across the treatment network. Can be used to determine if **the treatment network** is treating patients quickly and efficiently (as indicated by the died of complications and still in system statistics). This report can be used in conjunction with the Patients by disposition at each level of care report to pinpoint specifically which levels of care are problematic.
Patients by patient condition category	Table, pie chart	Shows the numbers of patients with each type of JRCAB patient condition category (e.g., head, gastrointestinal, respiratory).	Provides visibility on the distribution of the types of diseases and injuries generated within a certain theater. Can be used to determine the particular personnel skills required for a scenario.
Patients by disposition at each level of care	Table, pie chart	Shows the numbers of died of wounds, died of complications, returned to duty, still in system, and evacuated.	Provides visibility of the distribution of patient dispositions at level of care. Can be used to determine if **a level of care** is treating patients quickly and efficiently (as indicated by the died of complications and still in system statistics).
Assumptions	Table	Lists all the underlying assumptions for the Casualty Generation reports.	
Care Providing			

Report	Formats	Information in Report	Value to Medical Planners
Casualty time in system by level of care	Table	Shows patient information, such as how many arrive at and exit the level of care, average wait time for a task and for evacuation, total treatment time at the selected level of care.	Can be used to determine if enough personnel are present to provide treatment at the selected level of care. Can be used in conjunction with the Casualty time in system by functional area report to determine which functional areas within the level of care are problematic.
Casualty time in system by functional area	Table	Shows patient information, such as how many arrive at and exit the level of care, average wait time for a task and for evacuation, total treatment time, at the selected functional area.	Can be used to determine if enough personnel are present to provide treatment at the selected functional area.
Casualty accumulation by level of care	Step chart	Shows the number of casualties either receiving or waiting for treatment at a particular time at the selected level of care.	Provides visibility on when congestion occurs within **the level of care**. Can be used to determine how to relieve congestion with additional personnel or transportation assets. Can be used in conjunction with the Casualty accumulation by functional area report to determine which functional areas within the level of care are problematic.
Casualty accumulation by functional area	Step chart	Shows the number of casualties either receiving or waiting for treatment at a particular time at the selected functional area.	Provides visibility on when congestion occurs within **the functional area**. Can be used to determine how to relieve congestion with additional personnel or transportation assets.
Casualty flow	Table	Shows the final disposition, arrival time, treatment time, and time since wounding for each casualty at each level of care in the system.	Provides visibility on how long each patient is in treatment. Can be used to determine if casualties are being treated efficiently through **the treatment network**. Can be used in conjunction with the Casualty flow by level of care to determine which level of care is problematic.
Casualty flow by level of care	Table	Shows the final disposition, arrival time, treatment time, and time since wounding for each casualty for the selected level of care.	Provides visibility on how long each patient is in treatment. Can be used to determine if casualties are being treated efficiently at the selected **level of care**.
Consumable usage by functional area	Table	Shows the starting and ending quantities, the quantity used, the time the quantity was exhausted (if applicable), and the casualty being treated when the consumables were exhausted at the selected functional area.	Can be used to determine which consumables are in high demand and which are over or under supplied.
Equipment utilization by functional area	Table, Gantt chart	Shows the percent of time of the scenario that each equipment item was used at the selected functional area.	A high-level report that can be used to determine whether certain equipment assets are under used and therefore if the number of assets designated for the scenario should be reduced. This report is best used as a decision tool only if the utilization percentages are very low. This is because

Report	Formats	Information in Report	Value to Medical Planners
			although an equipment asset may be used a percent of the total scenario time, the time it is used could be due to a spike in casualties during which more equipment assets were needed to address the needs of the patients.
Personnel utilization by functional area	Table, Gantt chart	Shows the percent of time of the scenario that each staff person was used at the selected functional area.	A high-level report that can be used to determine whether certain personnel are under used and therefore if the number of assets designated for the scenario should be reduced. This report is best used as a decision tool only if the utilization percentages are very low. This is because although each staff person may be used a percent of the total scenario time, the time each person is used could be due to a spike in casualties during which more staff were needed to address the needs of the patients.
Tasks performed by functional area	Table	Shows for each casualty the individual tasks performed, the supplies used by that task, the time the casualty arrived at the task, the time the task was started, and the time the task was finished at the selected functional area	Can be used to determine the skill set required to successfully treat the patient stream and to determine whether the personnel assets meet the requirements of the scenario.
Assumptions	Table	Lists all the underlying assumptions for the Care Providing reports.	
Transportation			
Transportation usage by pool	Table	Shows the number of trips made by all the assets, the average number of casualties per trip, the percent of trips without any delay, average delay for those trips with a delay, the total trip time for all assets at the selected functional area	Can be used to determine if enough transportation assets are available to handle the evacuation needs of the scenario by looking at the delay in evacuating patients **across all transportation assets**.
Transportation details by level of care	Table	Shows for each individual transportation asset the time requested, the casualty IDs for those on the asset, the time the asset left its home base, the time it arrived and departed from the level of care, the time it arrived at the home base, and the time the unloading of patients was complete at the selected level of care.	Can be used to determine if enough transportation assets are available to handle the evacuation needs of the scenario by looking at the delay in evacuating patients for **each asset**. In addition, it can be used to determine which assets are carrying the majority of the evacuation load and whether these assets can be more efficiently distributed to the levels of care in the treatment network.
Transportation utilization	Table, Gantt	Shows for each individual transportation asset the	Can be used to determine whether certain transportation assets are under used and therefore

Report	Formats	Information in Report	Value to Medical Planners
	chart	percent of time of the scenario that asset was used across all levels of care.	if the number of assets designated for the scenario should be reduced. This report is best used as a decision tool only if the utilization percentages are very low. This is because although a transportation asset may be used a percent of the total scenario time, the time it is used could be due to a spike in casualties during which more assets were needed to address the needs of the patients.
Assumptions	Table	Lists all the underlying assumptions for the Transportation reports.	

The general reports provide summary information on user inputs. In addition, TML+ creates an audit report, a detail intensive listing of each process completed by TML+. This report is not only useful for debugging purposes but can be used to obtain information currently not provided by other reports. In addition, TML+ provides assumption reports that make visible the assumptions of the program's simulation processes and data.

The casualty generation reports include the numbers and types of patients, the disposition of patients at each LOC, the distribution of PCs across patient categories. The reports are useful for determining if the treatment network is adequately providing the personnel mix and treatment facility capabilities necessary to treat the patient stream.

The care providing reports include time-in-system information, the number of patients being treated at a functional area at one time, patient arrival time and treatment times, and consumable, equipment, and personnel usage. These reports are valuable for providing visibility on which LOCs may have congestion, for determining if the treatment network is treating patients quickly and efficiently, and for assessing whether the network has enough personnel, consumables, and equipment.

The transportation reports include the number of evacuation trips per asset, trip times, average wait time for evacuation. These reports are valuable for assessing if the network has enough assets to meet the evacuation needs of the patient stream, and if they can be better distributed throughout the network.

Importantly, the reports described above are only a subset of the possible reports that TML+ can provide. Because of the open architecture of the program and the filtering and sorting capabilities of Access, the TML+ reporting module can be tailored to report any information the user deems valuable.

FUTURE WORK

NHRC is currently working to expand TML+ in four areas. One, TML+ will modularize medical capability by grouping medical tasks into capabilities-based sets. For example, the resuscitation module would include all those tasks necessary to resuscitate a patient at a specific functional area. Thus, users will have the ability to build a level of care from scratch; the user will customize the medical capability of a facility by identifying its modular medical capabilities as well as the quantity and types of supplies and personnel required to perform those capabilities.

Two, TML+ will incorporate a Geographical Information Systems (GIS) map on which users build their treatment network. The GIS map enhances the ability to manage spatial data, providing a more realistic geographical understanding of the terrain within the synthetic theater of operations. In addition, the GIS mapping system will facilitate the calculation of distances between POIs and levels of care.

Three, TML+ will also incorporate information useful for equipment simulation-based acquisition. Such data will include when each equipment item needs maintenance or repair and how many times it can be used before it needs to be replaced. This information will be useful in determining the quantity of equipment items for a scenario as well as how the operational capability of these items impacts the treatment of the patient stream.

Four, TML+ will include a smart reporting feature that compares reports from different runs; as users make changes and rerun the simulation, they will be able to compare the same reports across runs to make visible how the modifications to their scenario influenced specific metrics in the processes involved in providing medical care.

CONCLUSION

The use of TML+, as a program that models the flow of patients through a network of treatment facilities, has at least two implications for the medical planning process. First, TML+ is an analysis tool that can perform different types of planning. In deliberate planning, TML+ can be used before deployment to determine the medical assets and the medical treatment network that would optimally treat the expected patient stream. In crisis-action planning, TML+ can be used during deployment to reconfigure the medical treatment network in response to contingency events. In near real-time planning, TML+ can be used to track how patient treatment and evacuation events proceed as the mission is performed. This versatility provides medical planners and providers with a well-rounded view of the medical requirements for a particular mission as well as helps planners respond quickly and efficiently to the rapidly changing warfighting environment.

Second, TML+ is a research tool that can help identify the best course of action for the anticipated patient stream with the projected assets. For example, TML+ can be used to determine whether a particular medical treatment facility can successfully handle a specific patient stream; how the relocation of a treatment facility affects patient treatment; which and how much of the supply, personnel, and transportation assets are utilized by the expected patient stream; and whether one network of care facilities is more efficient for treating patients than another network of care facilities. Such research can be used to both determine how to best configure and employ those assets already secured and to justify the procurement of additional assets to ensure a high standard of medical care.

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